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HIGH ENERGY EFFICIENT SOLID STATE LASER SOURCES

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ABSTRACT

We continue our investigations of diode-laser-pumped solid-state laser oscillators and non-linear processes using them as sources. Diode laser array pumped Nd:YAG and Nd:glass slab lasers have been demonstrated. Theoretical studies of non-planar oscillators have been advanced, producing new designs which should be much more resistant to feedback and offer better frequency stability. A monolithic, singly resonant Optical Parametric Oscillator in $MgO:LiNbO_3$ has been operated.

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I. Introduction.

The objective of this program is to perform basic research and to develop technology for solid state lasers for remote sensing and communication applications. Our recent efforts have been concentrated on the refinement of the high-stability diode-pumped nonplanar ring laser design. We have frequency doubled the output of these nonplanar ring lasers using external cavity second harmonic generation. We have also demonstrated high power operation of diode laser array pumped Nd:glass and Nd:YAG lasers. We have explored new wavelengths by demonstrating operation of a monolithic $MgO:LiNbO_3$ singly resonant OPO.

The consistent theme of the program has been the use of semiconductor diode lasers for high efficiency and high frequency stability applications. Diode pumping is efficient in the sense that pump radiation is focussed entirely in the mode volume and has its energy entirely in the absorption band of the lasing ions, leading to low thresholds and outstanding slope- and wallplug efficiencies. It is also efficient in the sense that the solid state laser (or non-linear process) has far greater coherence than the pumping laser, leading to orders of magnitude improvement in spectral brightness.

The dramatic decrease in the cost of semiconductor diode lasers used in compact disc players demonstrates the capabilities of present mass production techniques. Similar production techniques can be used to produce the higher power laser diodes used for pumping solid state lasers, so that it is reasonable to expect the price of the higher power diode lasers to decrease from their current high level. As these high power devices become available in larger quantities and at significantly lower prices, the all-solid-state technology that we have been developing under this program should replace flashlamp-pumped lasers entirely.

II. Research Progress.

In the past six months of this program, our efforts have concentrated on two main areas. These are the use of high power diode laser arrays to pump slab neodymium lasers and the operation of a monolithic OPO pumped by a highly coherent source.

In the past, our efforts have concentrated on using diode lasers to longitudinally pump solid state lasers of small mode volumes. This pumping geometry allows the devices to be highly efficient, since the pump energy is deposited only in the lasing volume. Unfortunately, this end pumped geometry does not scale well to higher pump powers, due to thermal stresses that are induced when pumping into a small volume, and to difficulty with focussing large array outputs into the small mode volume. The use of high power diode arrays is especially well suited for pumping slab geometry solid state lasers. The slab geometry allows efficient coupling of the exponentially absorbed pump radiation to the laser mode.

In a collaborative experiment with Spectra Diode Laboratories, we used a 380-W-peak-power GaAlAs diode laser array to pump miniature laser slabs of both Nd:YAG and Nd:Glass [a]. We fabricated slabs of 0.7% doped Nd:YAG and of 3%, 6% and 8% doped Nd:Glass. The slabs were designed to oscillate with three internal reflections per pass and with entrance faces close to Brewster's angle to minimize losses. The Nd:YAG slab was 4.6 mm thick and the glass slabs were 2 mm thick. One slab face was placed as close as possible to the emitting surface of the array. A flat silvered mirror was placed next to the slab opposite the array to reflect pump light not absorbed on the first pass.

The diode array was operated with 200-μs duration pulses rectangular in time. Our available selection of cavity mirrors did allow us to optimize cavity outcoupling for the YAG laser but not for the glass laser with its much lower internal losses but lower gain cross section. The YAG laser had a 20-mJ threshold and 23% slope efficiency when a 10% outcoupler was used. Slope efficiency was lower for the glass laser ranging from 6% to 13% with the 3% doped glass slab having the lowest efficiency and the 8% doped slab having the highest. Analysis of the data showed that both the YAG and glass laser materials had approximately 43% laser storage efficiency. Scaling these devices to

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[a] Murray Reed, W. J. Kozlovsky, and R. L. Byer "Diode Laser Array Pumped Neodymium Slab Oscillators", Submitted to Optics Letters

higher powers should be simple when higher power diode arrays become available. Increasing the pump area or power density should lead to slope and extraction efficiencies approaching 40%.

Our research on the frequency conversion of the frequency stable output of our frequency stable diode laser pumped NPROs has also continued. We have demonstrated optical parametric oscillation in $MgO:LiNbO_3$, pumped by the frequency doubled output of the diode-pumped non-planar ring oscillator and multiple pass zig-zag slab amplifier (developed for our 1.06-μm coherent LIDAR experiments). This is an ideal pump for an OPO since it provides single-mode long-pulse frequency-stable output . The millijoule output from this system was first doubled in a 2.5-cm-long crystal of $MgO:LiNbO_3$. The resulting 532-nm light was then used to pump a $MgO:LiNbO_3$ singly resonant OPO. The OPO was designed to operate with the resonant signal in the range of 850-950 nm and non-resonant idler in the range 1420-1210 nm. The monolithic construction provided a stable resonator structure, and the wavelength range was chosen to allow beat frequency experiments with Nd:YAG lasers operating at 946 nm and 1320 nm, determining of the frequency stability of the OPO. Extension to other wavelengths will follow after the initial characterization of the OPO.

The measured OPO threshold was 70-watts peak power in a 500-nsec-long pulse, in good agreement with theory. When pumping at two times threshold, the turn-on time of the OPO was approximately 200 nsec, after which time 20 % pump depletion was observed. This agreed well with the measured ~ 10 % total conversion of the pump energy to OPO output energy. We were able to tune the output of the OPO from 835 nm to 958 nm by adjusting the temperature of the crystal from 188 C to 122 C. This wavelength range makes possible linewidth studies of the OPO by allowing beat frequency measurements against nonplanar ring oscillators operating at 946 nm or 1320 nm..

III. Planned Future Research.

The future planned experiments in this program are contingent on receiving additional research funds requested in the addendum proposal. We are interested in continuing work on the OPO to study its linewidth properties. This will be possible by performing beat frequency measurements against diode pumped Nd:YAG nonplanar ring oscillators operating at 1.32 μm. These sources will also allow studies of the injection seeding properties of OPOs.

IV. Publications and Presentations

A. Publications

1. T. Y. Fan, G. Huber, R. L. Byer, and P. Mitzscherlich, "Continuous-wave operation at 2.1 μm of a diode-pumped, Tm-sensitized Ho:$Y_3Al_5O_{12}$ laser at 300 K," Opt. Lett. **12**, 678 (Sept. 1987).

2. T. Y. Fan and R. L. Byer, "Continuous-wave operation of a room-temperature, diode- pumped, 946-nm Nd:YAG laser," Opt. Lett. **12**, pp. 809-811 (Oct. 1987).

3. W. J. Kozlovsky, C. D. Nabors and R. L. Byer, "Second-harmonic generation of a continuous-wave diode-pumped Nd:YAG laser using an external resonant cavity," to be published, Optics Letters, December 1987.

B. Invited presentations

1. Robert L. Byer, "The Renaissance in Solid-State Lasers," R. V. Pole Memorial Lecture and Plenary Paper MI1, Conference on Lasers and Electro-Optics, Baltimore, April 27 - May 1, 1987.

2. R. L. Byer, "Advances in Diode Laser Pumped Solid State Lasers," Australian Conference on Lasers and Spectroscopy (ACOLS '87), Surfers Paradise, Queensland, Australia, May 1987.

3. R. L. Byer, S. Basu, T. Y. Fan, W. J. Kozlovsky, C. D. Nabors and A. Nilsson, "Diode Pumped Solid State Laser Oscillators for Spectroscopic Applications," presented at the Eighth International Conference on Laser Spectroscopy, Åre, Sweden, June 22-26, 1987.

4. Robert L. Byer, "Diode-Pumped Solid-State Lasers for Optical Radar," AFIT Distinguished Lecture, AFIT School of Engineering, Wright Patterson Air Force Base, Ohio, August 12, 1987.

5. R. L. Byer and T. Kane, "Diode Pumped Solid State Lasers for Remote Sensing," Topical Meeting on Laser and Optical Remote Sensing: Instrumentation and Techniques, North Falmouth, Cape Code, Mass., September 28 - October 2, 1987

C. Contributed presentations

1. T. Y. Fan, G. Huber, R. L. Byer and P. Mitzscherlich, "Continuous Wave Diode Laser Pumped 2-µm Ho:YAG Laser at Room Temperature," paper FL1, Conference on Lasers and Electro-Optics, Baltimore, April 27 - May 1, 1987.

2. T. Y. Fan and Robert L. Byer, "Diode Laser Pumped 946-nm Nd:YAG Laser at 300 K," paper FL3, Conference on Lasers and Electro-Optics, Baltimore, April 27 - May 1, 1987.

3. W. J. Kozlovsky and R. L. Byer, "External Resonant Cavity Frequency Doubling of a Diode- Pumped Nd:YAG Laser," paper FL5, Conference on Lasers and Electro-Optics, Baltimore, April 27 - May 1, 1987.